Poster I-28

A Method To Identify Mechanical Factors Causing Bone Degradation and To Deduce Diagnostics for Osteoporosis

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Osteoporosis is one of the major health problems in western societies. Since is essential to be able to reliably identify subjects requiring therapy. Bone density, which is currently the principal means for detecting osteoporosis (World Health Organization), is known to only partially account for bone strength. It has been well-established that factors such as the levels of connectivity and anisotropy of the inner porous segments of bone (trabeculae) play therapeutic agents used to reduce bone degradation have adverse side-effects, it a significant role in determining the strength of vertebral and other bones. Reliability of diagnostic tools can only be enhanced by properly accounting for the consequences of these multiple facets.

We have used a mathematical model consisting of disordered cubic networks of struts and nodes to represent porous bone. The freedom to implement independent changes provides means to deduce those factors which cause largest reductions in bone strength. In particular, it is found that reduction in number of trabecular elements is the leading cause of loss of bone strength. Using this observation, we are able to identify a new characteristic that can act as a surrogate for fracture load. A model that can be subjected to theoretical and numerical analysis led to the following results:

1. With advancing degradation, bone becomes increasingly less efficient at load transmission. A healthy bone is typically used in its entirety to transmit loads. In contrast, only a small fraction of a weak bone can be used for the task. Consequently, reduction in the strength of a bone is nonlinearly related to its density.
2. We have used fracture mechanics and percolation theory to establish an expression relating the breaking strength of a bone and loss of bone material. Previously published data on the strength of bone samples from the iliac crest and vertebrae in humans ranging in age from 20-90 years were shown to be consistent with the new expression.
3. A new surrogate for the breaking strength of a bone was identified from the analysis of the mathematical model. The measurements required are (1) the elastic modulus of a bone sample, and (2) its response to high frequency ultrasonic vibrations. Techniques are currently available to conduct these measurements.

These conclusions were validated using computations on digitized images of bone samples obtained using micro computed tomography. They are synthetically degraded by ``shaving" voxels lying on the surface. In order to perform computations, each voxel is replaced by a suitable combination of elastic elements along the edges and face-diagonals of each cube. Computations conducted on these lattice spring models have supported conclusions derived from the mathematical model. In future studies, we expect to perform direct experimental tests using vibrational analysis on bone samples and on prototyped duplicates.

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